

Energy Efficiency in Multicast Multihop D2D Networks

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Abstract—As the demand of mobile devices (MDs) for data services is explosively increasing, traditional offloading in the cellular networks is facing the contradiction of energy efficiency and quality of service. Device-to-device (D2D) communication is considered as an effective solution. This work investigates a scenario where the MDs have the same demand for common content and they cooperate to deliver it using multicast multihop relaying. We focus on the problem of total power minimization by grouping the MDs in multihop D2D networks, while maintaining the minimum rate requirement of each MD. As the problem is shown to be NP-complete and the optimal solution can not be found efficiently, two greedy algorithms are proposed to solve this problem in polynomial time. Simulation results demonstrate that lots of power can be saved in the content delivery situation using multihop D2D communication, and the proposed algorithms are suitable for different situations with different advantages.

I. INTRODUCTION

Recent communication systems are confronted with explosive growth in mobile applications. It is reported that people more frequently use their mobile devices (MDs) to connect, follow social media, watch live shows, etc. Therefore, the increase of data demands requires efficient cellular technologies to remain users' quality of service. The traditional cellular network technique is not capable of meeting future's service needs.

Offloading cellular networks is highly attracting attention in recent years by either migrating to new network topologies or developing enhancement techniques of current cellular networks to accommodate more subscribers with higher data rates [1]–[8]. A number of cellular offloading techniques have been proposed in the literature, such as switching to femtocells [9], [10] or Wi-Fi networks [3], [11]. These techniques have a range of advantages including low cost, standardized interface and high quality of services. Another technique would be content multicast to MDs on the cellular network [5], [12]. This technique performs well in high density of MDs requiring the same content. Nevertheless, a major problem of multicast is the limitation that all MDs download content by an identical rate decided by the worst channel among all MDs, which may sacrifice the performance of MDs in better channel conditions. Another attractive technique is to deliver content cooperatively in which MDs act as relays and connect other MDs with no congestion [1], [6], [13]–[18].

The concept of device-to-device (D2D) communications is to establish direct links between MDs and bypass the base

station (BS). Cooperative D2D communication shows a good potential for content delivery (e.g., files, videos, live shows, etc.) [3], [13]–[17]. The D2D-enabled cellular offloading can be realized by the following ways. One is that BS divides the content into different chunks and distributes them to different MDs. Then MDs exchange the chunks via an ad hoc manner until all MDs receive the complete content. Consequently, only a few copies of the content are delivered by cellular network instead of the entire content [7]. Another direction is group-based multicast in multihop D2D networks where content is relayed group by group using multicast. However, this scenario is much less investigated in the literature.

The idea of multicast in multihop networks has many advantages. First, it can considerably offload traffic of BS. Most importantly, the total power consumption can be significantly reduced since the distances between MDs are much shorter than the distances between BS and MDs. Moreover, edge MDs far from BS can gain much better transmission from their close multicast groups. However, this idea depends on how to group MDs and form the multicast links. This is very challenging as MD grouping usually falls into NP-complete problem even in a single-hop case.

Several works have been done on multicast D2D networks. For example, the authors in [19] compared Wi-Fi cooperation and D2D-based multicast content distribution in terms of time-saving and power-saving. However, how to group MDs was not discussed. In [20], grouping multicast was considered for delay and throughput problems. In the work, the groups were assumed to be fixed. In [7], fairness constraint was imposed to user grouping for channel allocation.

To our knowledge, there is no work on total power minimization with group multicast in cooperative multihop D2D networks. Our aim is to find an efficient power minimization strategy to group MDs by multicast transmission while maintaining rate requirements of all MDs. The multicast groups are connected via multihop relaying fashion. The problem has no optimal solution with polynomial time complexity. Thus we alternatively propose two heuristic algorithms to balance the performance and complexity. Each algorithm has its own advantages and disadvantages. The simulation results verify the effectiveness of the proposed algorithms.

The rest of the paper is organized as follows. Section II describes the system model, including main parameters and problem formulation. Section III proposes two efficient algo-

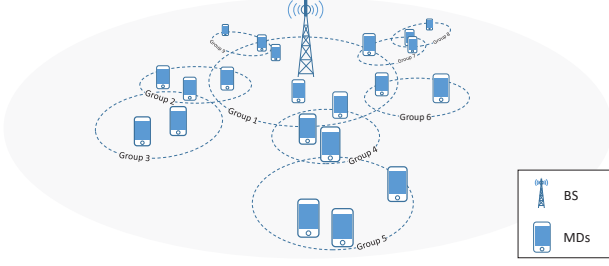


Fig. 1: Content delivery in multicast multihop D2D network.

rithms. Simulation results and analysis are shown in Section IV. Finally, conclusions are made in Section V.

II. SYSTEM MODEL AND PROBLEM FORMULATION

We consider a cellular network where the MDs tend to obtain the same content from the single BS, denoted as set $\mathcal{C} = \{1, \dots, C\}$. As discussed previously, no matter how many services MDs request and how good the wireless environment they are in, BS should always be ready for transmission. Therefore, the load of BS is considerably heavy, especially when MDs are active.

In addition, a MD will consume many resources if it requests for a large content. This kind of data demands is popular such as file downloading and sharing. Consequently, maintaining sufficient energy storage becomes a great challenge to any cellular system. To deal with this problem, we consider the scenario that MDs offload the traffic of BS using D2D communication. That is, each MD can receive content either from BS or other MDs through multiple hops as shown in Fig. 1.

The D2D-enabled content distribution process is carried out as follows: Firstly, when new content is available in BS and can be downloaded, the BS chooses a subset of MDs and multicasts the content to them. The required service rates of the selected MDs in the subset should be satisfied. Then, the rest of MDs can obtain the same content from those MDs receiving content from the BS. These MDs form disjoint subsets according to certain grouping rules and each subset chooses its appropriate multicast transmitter. This procedure is repeated until all MDs are grouped and their required rates are maintained. In another word, the content delivery process is carried out group by group using multihop relaying.

A. Parameters and Variables

We present the main parameters and variables in Table I.

In this paper, we consider the wireless channel gain from MD m to MD n as the following model:

$$h_{mn}(\text{dB}) = \frac{P_{r,mn}(\text{dB})}{P_{t,mn}(\text{dB})} = \underbrace{10 \log_{10} K - 10\beta \log_{10} \frac{d}{d_0}}_{\text{pathloss}} - \underbrace{\varphi_{\text{dB}}}_{\text{shadowfading}} \quad (1)$$

TABLE I: MAIN PARAMETERS AND VARIABLES

Parameters	
\mathcal{C}	The set of MDs $\mathcal{C} = \{1, 2, \dots, C\}$
$P_{t,mn}$	Transmit power of transmitter m to n
$P_{r,mn}$	Receive power at MD n from transmitter m
β	The path loss exponent
N_0	The noise power density
\mathcal{K}_{s_j}	The multicast group consists of MDs receiving content from transmitter s_j
$R_g(\mathcal{K}_{s_j})$	The multicast rate of group \mathcal{K}_{s_j}
d_0	A reference distance of the antenna far-field
h_{mn}	The channel quality exponent between MD m and MD n
x_{mn}	A binary variable that indicates whether the condition of channel between MD m and MD n is the worst in the multicast group transmitted by MD m
y_{mn}^h	A binary variable indicates whether MD m transmits content to MD n on hop h
R_{\min}	The required rate of all MDs
H_{\max}	The maximum of the number of transmit hops
\mathcal{R}	The set of receivers have not yet get content
\mathcal{S}	The set of potential transmitters containing content
\mathcal{K}	The set of disjoint multicast among multiple hops

where $P_{t,mn}$ and $P_{r,mn}$ are the transmit power and received power between transmitter m and receiver n , respectively; K is a constant which depends on the characteristics of antenna and the attenuation of average channels; d_0 is a reference distance (1-10 meters indoors and 10-100 meters outdoors) of the antenna far-field; β is the path loss exponent; φ_{dB} is Gauss-distributed random variable with mean zero and variance $\sigma_{\varphi_{\text{dB}}}^2$; d is the distance between a transmitter and a receiver.

Given the transmitter m , the achievable rate of MD n is given by

$$R_n = \log_2 \left(1 + \frac{h_{mn} P_{t,mn}}{N_0} \right), \quad (2)$$

where N_0 is the noise power density. For the multicast case, the bit rate R_n should follow the Short Slab theory, which means that the rate is limited by the worst channel. Assume that there is a multicast group \mathcal{K}_{s_j} where s_j acts as the transmit node, it uses multicast to serve all MDs. The maximum multicast rate $R_g(\mathcal{K}_{s_j})$ is given by

$$R_g(\mathcal{K}_{s_j}) = \log_2 \left(1 + \frac{\sum_{\forall m, n \in \mathcal{K}_{s_j}} h_{mn} P_{t,mn} x_{mn}}{N_0} \right) = \log_2 \left(1 + \frac{h_{mw'} P_{t,mw'}}{N_0} \right), \quad (3)$$

where w' is MD with the worst channel quality in multicast group \mathcal{K}_{s_j} , which means $R_g(\mathcal{K}_{s_j}) = \min R_n, n \in \mathcal{K}_{s_j}$. The required transmit power depends on the decodable rate. That is, for given quality of service demand R_{\min} . The transmit power is computed by $P_{t,mn} = (2^{R_{\min}} - 1)N_0/h_{mn}$.

B. Optimization Problem Formulation

Our goal is to minimize the total transmit power consumption of the whole network by optimizing multicast group

division while maintaining the minimum achievable rate of each MD. The problem can be mathematically formulated as

$$\min_{P_{t,x},y} \sum_{m=1}^C \sum_{n=1}^C P_{t,mn} x_{mn} + P_{(BS)} \quad (4)$$

$$\text{s.t. } x_{mn} \leq y_{mn}^h, \quad \forall m, \forall n \in \mathcal{C}, 2 \leq h \quad (5)$$

$$y_{mn}^h \leq y_{(BS)m}^1, \quad \forall m, \forall n \in \mathcal{C}, 2 \leq h \quad (6)$$

$$y_{ji}^h \leq \sum_{k=1}^C y_{kj}^{h'}, \quad h' = 1, \dots, h-1 \quad (7)$$

$$R_{min} \leq R_g(\mathcal{K}_{s_j}), \quad \forall \mathcal{K}_{s_j} \subseteq \mathcal{K} \quad (8)$$

$$\sum_{h=2}^{H_{max}} \sum_{m \neq n}^C y_{mn}^h + y_{(BS)n}^1 = 1, \quad \forall n \quad (9)$$

$$h \leq H_{max}, \quad \forall h \quad (10)$$

where x_{mn} is a binary variable that indicates whether the channel condition between MD m and MD n is the worst in the multicast group transmitted by MD m ; y_{mn}^h is a binary variable indicates whether MD m transmits content to MD n on hop h ; R_{min} is the minimum rate requirement of all MDs to decode the same content; $R_g(\mathcal{K}_{s_j})$ is the multicast rate in the multicast group \mathcal{K}_{s_j} ; H_{max} is the predefined maximum tolerated hops to some extent delay considerations. The subscript BS represents the base station.

The objective (4) minimizes total transmit power of MDs and BS. Constraint (5) ensures that the transmission rate determined by the worst channel condition in a multicast group. Constraint (6) ensures that MD n can transmit on next hop only if it receives content from BS. Constraint (7) ensures that MD n can transmit content on next hop only if it receives the content on previous hop. Constraint (8) ensures that each multicast group \mathcal{K}_{s_j} should meet the minimum rate requirement R_{min} to ensure quality of service. Constraint (9) ensures that each MD can receive the content once among the total H_{max} hops transmission. Constraint (10) is the maximum hop tolerance, which is related to the delay problem in practice.

C. Complexity

The optimization formulation that minimizes the total power consumption by optimizing multicast group division while maintaining multihop delay and data rate is an mixed integer programming (MIP) problem. MIP problem is always NP-complete due to the binary variables [21]. Let α represents the number of binary variables and $\alpha = C^2 + H_{max}C^2$ in problem (4)-(10). The worst case complexity of determining the optimal result of this MIP problem is $\mathcal{O}(2^\alpha)$. The computational complexity of finding the optimal solution will increase exponentially as the number of MDs and transmit hops increases. Therefore, we turn to propose suboptimal methods with lower complexity in next section, which are suitable for practical communication systems.

III. PROPOSED SOLUTION - ALGORITHMS

In this section, we propose two heuristic algorithms. A core of a heuristic algorithm is to design a certain rule of choosing which MDs to connect with multicast in a multihop network. The two proposed heuristic algorithms are based on the different greedy rules and detailed in each subsection respectively.

A. Channel Gain Oriented Algorithm

In this algorithm, we assume that $H_{max} = C$, which is applicable for the case where the network has low-density MDs. We denote the initial set of transmitters $\mathcal{S} = \{s_1, s_2, \dots, s_j\}$ and the set of receivers $\mathcal{R} = \{r_1, r_2, \dots, r_i\}$, where s_j and r_i represent the j th transmitter and the i th receiver, respectively. Denote $\mathcal{K} = \{\mathcal{K}_{s_1}, \mathcal{K}_{s_2}, \dots, \mathcal{K}_{s_j}\}$ as final multicast groups and s_j is the transmitter of the multicast group \mathcal{K}_{s_j} . At the beginning of the algorithm, BS is the only element in \mathcal{S} , that is, the content delivery starts at BS. Meanwhile there are total C elements as MDs in \mathcal{R} . The grouping of MDs is realized by following procedure: when a new link is to be established, there is only one MD with the largest $h_{s_j r_i}/N_0$ is chosen from the \mathcal{R} as the receiver for s_j . The process continues until all MDs are linked. Specifically, assume that the i th MD in \mathcal{R} and its best channel condition is the link with the j th MD in \mathcal{S} . Then let the j th MD be the transmitter for the i th MD and the i th MD shifts from \mathcal{R} into \mathcal{S} and becomes a potential transmitter for next hops. Finally the MDs with a common transmitter are divided into the same multicast group.

Fig. 2(a) provides an example of the grouping process. In this example, there are 3 MDs (i.e., s_1 , s_2 , and s_3) in \mathcal{S} at the beginning. A MD is selected from \mathcal{R} if it has the largest channel gain with the already linked MDs. As shown in Fig. 2(a), links l_1, \dots, l_4 are successively established. After the whole D2D network is established as in Fig. 2(a), the MDs with the same transmitter are grouped together for multicast as shown in Fig. 2(b).

Algorithm 1 Greedy Channel Gain Oriented Solution

- 1: Initialize $\mathcal{S} = \{BS\}$, $\mathcal{R} = \{\mathcal{C}\}$, $\mathcal{K} = \emptyset$.
 - 2: **while** $\mathcal{R} \neq \emptyset$ **do**
 - 3: Select $s_j \in \mathcal{S}$ and $r_i \in \mathcal{R}$ that have the maximum $h_{s_j r_i}/N_0$
 - 4: Let MD s_j be the transmitter for MD r_i
 - 5: $\mathcal{K}_{s_j} \leftarrow \mathcal{K}_{s_j} \cup r_i$
 - 6: Update the sets of transmitters and receivers as
 - 7: $\mathcal{S} \leftarrow \mathcal{S} \cup r_i$
 - 8: $\mathcal{R} \leftarrow \mathcal{R} \setminus r_i$
 - 9: **end while**
 - 10: Calculate power consumption of each multicast group as (3).
 - 11: Calculate total power consumption of all groups.
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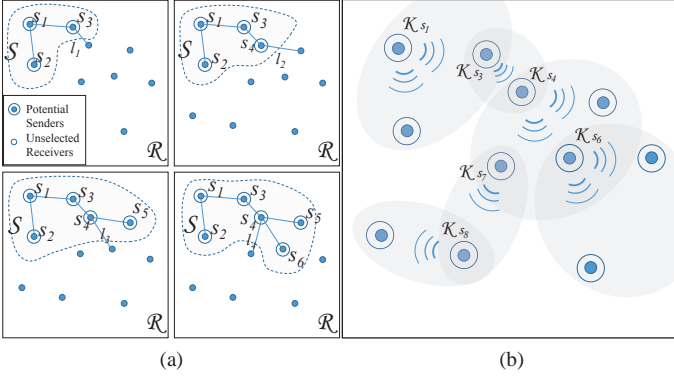


Fig. 2: (a) The grouping process of Algorithm 1. s_1, s_2, \dots, s_n are MDs in \mathcal{S} acting as potential transmitters. l_1, l_2, \dots, l_n represent the links with the maximum channel gain. (b) The multicast multihop D2D cooperative network is formed.

The total power consumption is the sum power consumption of all multicast groups that can be calculated by (3). Finally, we present the whole solution in Algorithm 1. In this algorithm, the transmitter set \mathcal{S} contains at most $(C+1)$ elements and the receiver set \mathcal{R} with C elements. The computational complexity of line 3 in Algorithm 1 is $\mathcal{O}(C^2)$ for finding the maximum values of channel gains. This step is repeated C times and thus, the complexity of Algorithm 1 is $\mathcal{O}(C^3)$.

Note that, the channel gain oriented algorithm may trigger the delay problem if the number of MDs goes to large. In addition, the complexity of this algorithm is $\mathcal{O}(C^3)$, which may be a little bit high for scenarios involving a large number of MDs. In the following subsection, we propose a cluster oriented algoithm with lower complexity.

B. Cluster Oriented Algorithm

Given the needed minimum rate R_{min} , the proposed cluster oriented algorithm aims to decrease total power consumption by minimizing the number of multicast groups, which is in part to minimize the number of transmitters. However this problem is NP-complete even in a single hop.

Theorem 1: The problem to determine the minimum number of transmitters on a single hop is NP-complete.

Proof: Assume each transmitter knows itself potential receivers. For example, $\mathcal{C} = \{\{1,3,4\}, \{2,3,5\}, \{2,4\}, \{1,4\}\}$, the MDs shown in boldface mean that they act as transmitters in subsets. Finally we choose $\{1,4\}$ and $\{2,3,5\}$ as the subsets which have the minimum number of subsets meanwhile cover all elements. This problem is similar to the set cover problem which is defined as follow: Given a set \mathcal{A} and disjoint subsets $\mathcal{A}_{s_1}, \mathcal{A}_{s_2}, \dots, \mathcal{A}_{s_j} \subseteq \mathcal{A}$, the goal is to select a minimum number of these disjoint subsets which contain all elements in \mathcal{A} . The set cover problem is NP-complete [22]. ■

The commonly used method for the set cover problem is greedy algorithm since it cannot be solved optimally in polynomial time. Here, we adopt the clustering idea into our problem, which follows the rule of selecting receivers as many as possible in a multicast group if the multicast channel gain is greater than a predefined threshold $h_{(set)}/N_0$ to satisfy the minimum rate R_{min} . This is because minimizing the number

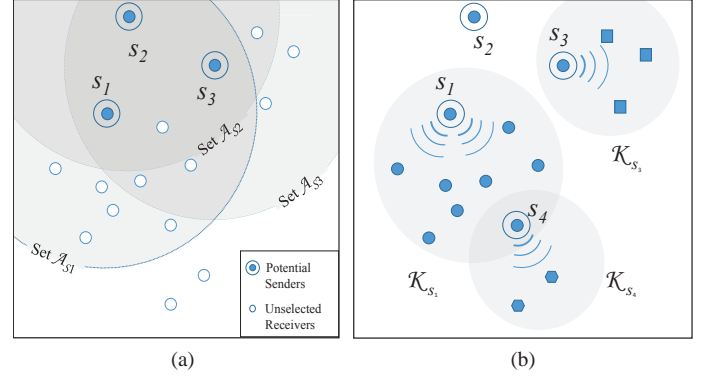


Fig. 3: An example for Algorithm 2.1. (a) Every MD that has already been linked starts to find out all unlinked MDs which can meet the rate constraint and form its own set. (b) According to the set cover rule, a transmitter with the largest set of receivers is priori to form group.

of transmitters also leads to minimizing total power consumption in some sense. We define that $\mathcal{A} = \{\mathcal{A}_{s_1}, \mathcal{A}_{s_2}, \dots, \mathcal{A}_{s_j}\}$, where the subset \mathcal{A}_{s_j} contains element r_i in \mathcal{R} (i.e., all uncovered MDs) if $h_{s_j r_i}/N_0 \geq h_{(set)}/N_0$. Note that it is possible that a MD may be selected by more than a transmitter (i.e., this MD is included by more than a subset of \mathcal{A}), so \mathcal{A} is not the final grouping result.

We present the greedy set cover method in Algorithm 2.1 to solve the grouping problem on a specific hop, where \mathcal{R} and \mathcal{A} are inputs and return \mathcal{K} as the final grouping result. At the beginning of this algorithm, \mathcal{I} heritages all elements from \mathcal{R} , a set of all the uncovered receivers. Consequently, the intersection of \mathcal{I} and \mathcal{A} equals to the set of uncovered MDs which maintains the minimum rate R_{min} (or equivalently the channel gain is greater than $h_{(set)}/N_0$). If there exists uncovered elements, the already covered MDs will cover the reminders on next hop. On each hop, a largest set of uncovered MDs satisfying the minimum rate R_{min} is selected to be a new multicast group \mathcal{K}_{s_j} with the transmitter s_j . Meanwhile, \mathcal{I} removes those MDs from \mathcal{A}_{s_j} since they are covered. It is worth noting that after each iteration, all possible sets of $\mathcal{I} \cap \mathcal{A}_{s_j}$ (i.e., uncovered MDs satisfying the minimum rate R_{min}) may be changed because some of their elements may already be removed from \mathcal{I} . Thus, by judging the size of $\mathcal{I} \cap \mathcal{A}_{s_j}$ instead of \mathcal{A}_{s_j} , the algorithm can correctly select the largest set from the reminders.

Algorithm 2.1 Greedy Set Cover Method

Step 1. $\mathcal{I} \leftarrow \mathcal{R}$.

Step 2. **while** $\mathcal{I} \cap \mathcal{A} \neq \emptyset$

a: select $\mathcal{A}_{s_j} \subseteq \mathcal{A}$ that maximizes $\{\mathcal{I} \cap \mathcal{A}_{s_j}\}$

$\mathcal{K}_{s_j} \leftarrow \mathcal{I} \cap \mathcal{A}_{s_j}$

b: $\mathcal{K} \leftarrow \mathcal{K} \cup \mathcal{K}_{s_j}$

c: $\mathcal{I} \leftarrow \mathcal{I} \setminus \mathcal{A}_{s_j}$

end while

Step 3. **return** \mathcal{K}

We take an example in Fig. 3 to illustrate the cluster oriented algorithm on a specific hop. Assume that transmitter set \mathcal{S}

contains three elements, i.e., $\mathcal{S} = \{s_1, s_2, s_3\}$. Subset \mathcal{A}_{s_1} , containing the most MDs which maintain the minimum rate R_{min} with transmitter s_1 , is formed and shown in Fig. 3(a).

Thus, the multicast group \mathcal{K}_{s_1} is formed after the first iteration. Then by removing \mathcal{K}_{s_1} from the set, \mathcal{K}_{s_3} is formed and thus the final grouping result is shown in Fig. 3(b).

In Algorithm 2.2, we present the whole algorithm to determine the grouping result in multihop. Note that there may exist some MDs which are uncovered as they cannot meet the request of $h_{(set)}/N_0$ within H_{max} hops. When such situation occurs, the algorithm reduces the channel threshold $h_{(set)}/N_0$ so that more MDs can be involved on each hop, and accordingly increases the transmit power to maintain the minimum rate constraint. The determining of $h_{(set)}/N_0$ is based on experiential simulations and we do not discuss the details in the paper.

Algorithm 2.2 Greedy Clustering Solution

- 1: Initialize $\mathcal{S} = \{BS\}$, $\mathcal{R} = \{\mathcal{C}\}$, $\mathcal{K} = \emptyset$, $h = 1$.
 - 2: **for** $h = 1$ to H_{max} **do**
 - 3: a. Update \mathcal{A} by adjusting transmit power and the pre-defined multicast channel threshold $h_{(set)}/N_0$ to satisfy the rate constraint.
 - 4: b. Run Algorithm 2.1 and obtain the grouping result \mathcal{K} on current hop.
 - 5: c. Update the sets of transmitters and receivers as.

$$\mathcal{S} \leftarrow \mathcal{S} \cup \mathcal{K}$$

$$\mathcal{R} \leftarrow \mathcal{R} \setminus \mathcal{K}$$
 - 6: d. Increase the number of hops $h = h + 1$
 - 7: **end for**
 - 8: Calculate power consumption of each multicast group as (3).
 - 9: Calculate total power consumption of all groups.
-

In Algorithm 2.2, the transmitter set \mathcal{S} contains at most $(C + 1)$ elements and the receiver set \mathcal{R} with C elements. Therefore, the complexity of forming set \mathcal{A} is $\mathcal{O}(C^2)$. Moreover, line 4 needs complexity of $\mathcal{O}(C^2)$ for finding subset with maximum number of elements. Since line 3 and line 4 are repeated at most H_{max} times and thus, the total complexity of the cluster oriented algorithm is $\mathcal{O}(H_{max}C^2)$.

IV. SIMULATION RESULTS

In this section, we evaluate the performance of the proposed algorithms. We set up the stimulation parameters as follows. MDs are randomly distributed within a circle area with a radius of 500 meters, where BS locates at the center point. MDs require the same content from BS. The noise N_0 is considered to be -100dBm. The channel parameters are: the constant K is -31.54dB, the path loss exponent is $\beta = 3$, $d_0 = 1$ m, and ϕ_{dB} is a zero-mean Gaussian random variable which represents the effects of shadow fading [23]. The required rate $R_{min} = 10$ (bit/s/Hz). H_{max} is considered to be C hops in the channel gain oriented algorithm and 10 hops in the cluster

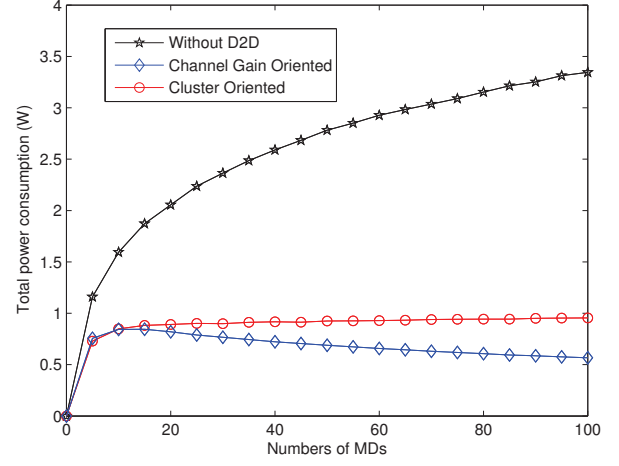


Fig. 4: The total transmit power versus the number of MDs.

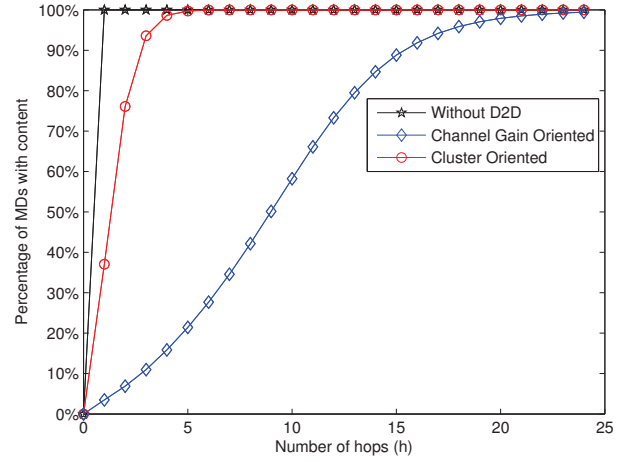


Fig. 5: The percentage of MDs with the content versus the number of hops when there are 100 MDs in total.

oriented algorithm. Each performance is simulated by Monte Carlo method with 10000 times.

Fig. 4 shows the total transmit power consumption by the channel gain oriented and the cluster oriented algorithm. The performance of BS broadcasting is also considered as a benchmark in the figure. Obviously, the two proposed algorithms have significant performance gain compared to the traditional scheme without multihop D2D cooperation. The reason is that MDs which are close to each other can guarantee high rate and consume much less power since they have shorter distances compared to that from BS. For the channel gain oriented algorithm, we observe that the power consumption goes down as the number of MDs increases if the number of MDs is greater than 10. This mainly attributes to that the increase of density lowers D2D distances generally and thus reduces the transmit power. For the cluster oriented algorithm, the variation of power consumption is much smaller than the channel gain oriented algorithm. The channel gain oriented algorithm performs the best in total power consumption but is at the price of its uncontrolled hops. Therefore, the channel gain oriented algorithm is better in performance of power-

TABLE II:
TOTAL POWER (W) VERSUS NUMBER OF MDS C

C	1	2	3	4	5	6	7
Algorithm 1	0.394	0.525	0.616	0.691	0.742	0.774	0.795
Algorithm 2	0.394	0.528	0.624	0.695	0.734	0.766	0.799
Optimal	0.394	0.509	0.573	0.638	0.654	0.709	0.739

saving if the content is delay-tolerant.

Fig. 5 shows that the channel gain oriented algorithm needs more hops than the cluster oriented algorithm. If there are 100 MDs, the channel gain oriented algorithm shows that up to 30 hops are required to make all MDs meet the rate constraint, while the cluster oriented algorithm just needs about 5 hops. This also means that remote MDs receive the content after waiting for a relatively longer time until previous MDs have obtained the content. In general, D2D networks formed by the cluster oriented algorithms have much less needed hops than that by the channel gain oriented algorithm and when the number of MDs increases, the difference continuously goes larger. As the number of hops arises, the stability of the network is undeniably affected by the multihop connections since the delay may become a problem. Such that, we can conclude that the cluster oriented algorithm is more favorable for cooperative multihop multicast in large networks if delay is an important issue.

We also compare the two proposed algorithms with the optimal situation obtained by exhaustive search in Table II. We can see that the performance of the two algorithms are close to each other and the difference between them is at most 0.01 W. When the number of MDs is small, the performance of the two algorithms are close to the optimal one.

V. CONCLUSION

This work addressed the energy efficiency of grouping solution in multicast multihop D2D cooperative network in a content distribution scenario. BS first multicasts content to a certain group of MD which act as relays and deliver it to other MDs in the next hops. A comprehensive optimization framework was presented for analyzing how to group MDs in order to reach a lowest total power consumption with the minimum rate constraint. This optimization problem is NP-complete. Therefore, two polynomial-time greedy algorithms were proposed to efficiently solve the problem. Simulation results showed that the total power consumption of the D2D cooperative multihop network is significantly less than that the traditional BS multicast network. In addition, the two proposed algorithms showed their individual advantages.

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